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SWAT BASED HYDROLOGICAL MODELLING OF KETAR WATERSHED, LAKE ZIWAY CATCHMENT, ETHIOPIA

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ABSTRACT

Water is abundant, yet frequently scarce and characterized by uneven spatial and temporal distribution. To utilize, manage and planning the available scarce resources of water, hydrological modelling and identification of temporal variability of water resources is very much essential. In line with this, the present study identifies temporal occurrence of water resources in Ketar watershed, Ethiopia and evaluates the Soil and Water Assessment Tool (SWAT) model performance capacity against measured data using graphical and statistical evaluation parameters. Input Flow parameters that affect model output are identified. The hydrology of the sub-basin is modelled using with dataset including soils, land use/cover, digital elevation model, flow and meteorological data from different meteorological stations located in the study area and the National Centre for Environmental Prediction's (NCEP) Climate Forecast System Reanalysis (CFSR) grids. The result showed that, SWAT model performs a good agreement between simulated and measured monthly stream flow during calibration and validation period. Therefore, it is proved to use the model for further simulations and analysis of Land use/land cover change on hydrological regime of Ketar watershed for future research.

KEYWORDS: SWAT Model, Hydrological Model, Ketar Watershed, Water Resource

INTRODUCTION

Of all the substances that are necessary to life on the earth, water is by far the most important to sustain life. Water is abundant, yet frequently scarce and characterized by uneven spatial and temporal distribution. Watershed characteristics from which fresh water occur and generated as stream flow can affect its quantity and quality. Watershed is a hydrologic unit which receives water as an end-product of the interaction of atmosphere, land surface and ocean systems. Stream flow is the main hydrological factor which influences the hydrological characteristics in many ways and shows their importance in balanced agricultural watersheds. To utilize, manage and plan the available scarce resources like water, hydrological modelling and identification of temporal variability of water resources is very essential.

Understanding the temporal occurrence of water resources at watershed level plays significant role in proper watershed management and for effective planing. Conducting simulation test of hydrological parameter against measured variable (i.e., stream discharge, sediment load etc) is become crucial in watershed management study as direct measurement reflects the true response of geo-spatial and physical alteration of watershed to farther cause and effect

analysis. There are several forces affecting hydrological system both in time and space (Legesse 2003), like demographic trends, climate variability, national policies, and macroeconomic activities that result in extensive alterations in land cover and land use. To evaluate impacts of land use and management practice on hydrological responses and sediment load in watershed, the model must be calibrated and validated with respect to observed data (Kassa and Foerch, 2007).

Hence, the main objectives of this particular study is to evaluate SWAT model performance capacity against measured data of water resource in Ketar watershed, Lake Ziway catchment, Ethiopia using graphical and statistical evaluation parameters.

STUDY AREA

Ketar watershed covers 3225.3 square kilometres (km^2) and is a part of the Ziway– Shala basin. This internal drainage basin is located in the central part of the Main Ethiopian Rift Valley (Figure 1). Geographically, it is located between 7°21'33" - 8°9'53" north latitude and 38°53'57" - 39°24'46" east longitude. Ketar River and its tributaries drain from south east highland area of Ethiopia to north west and enter Lake Ziway.

This lake is the most northerly of the Main Ethiopian Rift Valley lakes, and is fed principally by rivers draining from the south eastern and north western plateaux and escarpments. The over flow of Lake Ziway feeds Lake Abiyata to the south. Topographically, the Ketar catchment shows a well pronounced variation with the altitude ranging from around 1646 m above Mean Sea Level (MSL) near Lake Ziway (at the outlet) to about 4171 m above MSL on the high volcanic ridges along the eastern watershed Chilalo and Galama mountain.

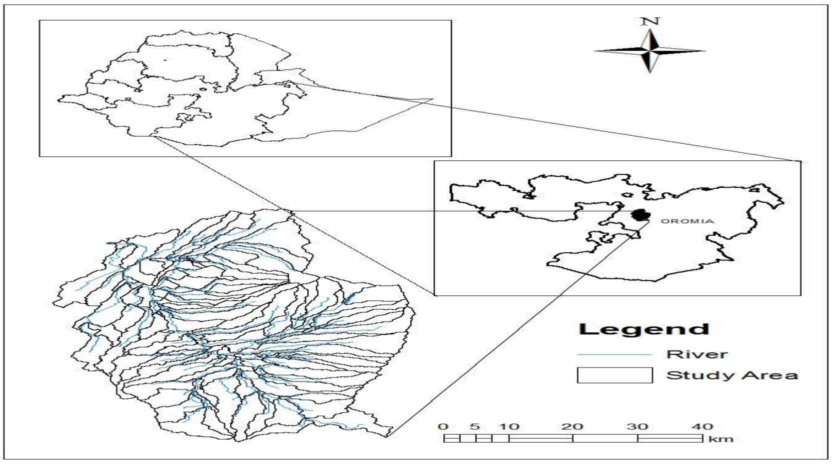

Figure 1: Location of the Study Area (Ketar Watershed)

METHODOLOGY

Application of SWAT Model

Soil and Water Assessment tool (SWAT) is physically based, river basin scale, computationally efficient, continuous-time model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in un-gauged catchment (Gassman et.al, 2007). SWAT model can be used for different purposes of applications in a watershed. For instance, Adeogun et. al. (2014) used SWAT models to predict water balance and water yield of a catchment area in Nigeria. It was suggested that, SWAT model could be a promising tool to predict water balance and water yield in sustainable management of water resource. Abbaspour et. al. (2006), applied SWAT models on Thur River basin, which is located in the north-east of Switzerland to simulate all related processes

affecting water quantity, sediment, and nutrient loads in the catchment. It was reported that, there are excellent results for discharge and nitrate and quite good results for sediment and total phosphorous as modelled by SWAT. Similarly, Tibebe and Bewket, (2010) also applied SWAT model to evaluate surface runoff generation and soil erosion rates for a small watershed (Keleta Watershed) in the Awash River basin, Ethiopia, and recommended that, the SWAT model provides a useful tool for soil erosion assessment from watersheds and facilitates planning for a sustainable land management.

SWAT is developed to examine the influence of topographic, land use, soil and climatic conditions on stream flow and sediment yield. This model can be utilized either from the source code or from the Geographic Information System (GIS) interfaces, which simplifies the integration of various spatial environmental data and the use of bulk data. It is a continuous time model and allows for simulation of different physical processes in a watershed. The spatial unit for rainfall-runoff calculations is the Hydrologic Response Unit (HRU), which is a lumped land area within a sub-watershed comprised of unique land cover, soil, slope, and management combinations. It is physically-based semi distributed watershed hydrological model, requires continuous time step, readily available data for simulating stream flow, sediment load, of watershed process as a result of land use land cover change and management practice, through calibration and validation of the model parameters.

The SWAT model application can be divided into six steps: (1) data preparation, (2) sub-basin discretization, (3) HRU definition, (4) parameter sensitivity analysis, (5) calibration and validation, and (6) uncertainty analysis.

Data Preparation and its Sources

Hydrological modelling using SWAT requires the use of spatially explicit datasets for land morphology or topography, land use or land cover, soil parameters for hydrological characteristics, and climate and hydrological data on a daily time step (Schuol and Abbaspour, 2007). In the case of the Ketar river basin, new, basin-specific datasets were developed from raw data sources for land use/land cover, soil, and slope and for weather condition. A complete list of variables and utilized data sources is presented in Table 1. The preparation of data is described as the following sections.

Table 1: Variables Used in the SWAT Model and Data Sources

Variables	Data Sources
Land use/land cover map	Landsat 5 thematic mapper (TM), Mapping Authority of Ethiopia
Soil map	RVLB Master plan, Ministry of Water and Energy of Ethiopia
Digital Elevation Model	Ethiopia Mapping agency
Stream flow	Hydrology and irrigation department of Ministry of Water and Energy of Ethiopia
Precipitation	National Meteorological Agency of Ethiopia, Addis Ababa
Temperature	National Meteorological Agency of Ethiopia, Addis Ababa

Land Use/Land Cover Data

Land use land cover and management is an important factor affecting different processes in the watershed, such as surface runoff, erosion, recharge and evapotranspiration. The land cover data were generated from the 30 meter resolution Landsat Thematic Mapper (TM) data 1986 obtained from Mapping Agency of Ethiopia (MAE). The look up table and the map LUC were prepared as per SWAT model format required and kept in SWAT data-base. The dominant land use land

cover in Ketar watershed was agricultural land, grassland, Afro-alpine vegetation and forestlands as presented in Table 2 and Figure 2.

Table 2: Dominant Land Use Distribution of Ketar Watershed

Land Use Type	Land Use Code	Area (Km^2)	Area (%)
Agricultural land	AGLD	1485.89	46.09
Rock out crop	ROCP	53.56	1.66
Forestland	FRLD	416.09	12.90
Built up area	BLUA	24.69	0.77
Grassland	GRLD	635.99	19.72
Afro-alpines	ALPN	604.7	18.75
Wetland	WTLD	4.36	0.14
Total		**3225.28**	**100**

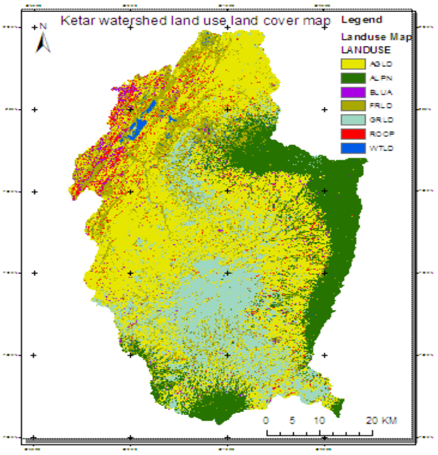

Figure 2: Land Use Land Cover Map in Ketar Watershed

Climate Data

Climate data used in the present SWAT model consist of daily rainfall, temperature, wind speed, humidity and solar radiation data. The weather variables used are the daily precipitation and the minimum and maximum air temperature values obtained from six monitoring stations in the study area vide Table 3, and one from National Centre for Environmental Prediction's (NCEP) Climate Forecast System Reanalysis (CFSR) grid stations (Global Weather, 2014). Local monitoring Climatic Variables between 1983-2010 years period for Ketar watershed are obtained from the National Meteorological Agency of Ethiopia, Government.

Table 3: Details of Weather Monitoring Stations in Ketar Watershed, Ethiopia

Name	Coordinates		Altitude AMSL (m)
	Latitude UTM	Longitude UTM	
Areta	880982	505510	1765
Asella	878773	514328	2413
Bokoji	832715	527580	2480
Kulumsa	884301	516530	2211
Ogolcho	889825	500000	1682
Sagure	856361	515178	2388
W76391	845563	506893	2560

Soil Data

The response of a river basin to a rainfall event depends on the nature and conditions of underlying soils (Shrestha et al., 2008). The SWAT model requires soil property data such as the texture, chemical composition, physical properties, and available moisture content, hydraulic conductivity, bulk density and organic carbon content for the different layers of each soil type. Soil data were obtained from Rift Valley Lakes Basin (RVLB) integrated resource development reconnaissance soil survey master plan study project, Ministry of Water and Energy of Ethiopia (MOWE, 2008). The spatial distribution of major soil type of study area is shown in Figure 3. The most widespread soil type in the Ketar watershed is Haplic Luvisols (LVh) consists of 40 % clay, 32 % silt, and 28 % sand. The second widely distributed soil type in the study area is Vertic Nitosols (NTr) consists of 48% sand, 33% silt and 19% clay. The soil properties vide table 4, specific for the Ketar River sub-basin soils are appended to the SWAT data-base, because the soil types found in the study area are not included in the US soils database provided with SWAT.

Table 4: Detailed Distribution of Soil Type in the Ketar Watershed

Types of Soils	Textural Distribution/Composition			Area (Km^2)	Area (%)
	Sand %	Silt %	Clay %		
Haplic Luvisols (LVh)	28	32	40	1863.46	57.78
Vertic Andosols (ANz)	46	40	14	118.93	3.69
Vertic Nistosols (NTr)	48	33	19	1042.41	32.32
Eutric Cambisols (CMe)	25	31	44	0.05	0.00
Eutric Vertisols (VRe)	32	39	28	198.67	6.16
Total				**3223.52**	**100.00**

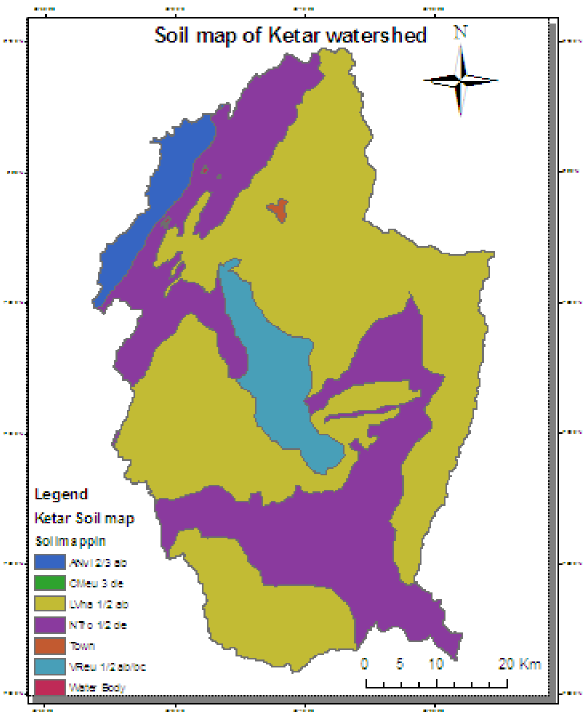

Figure 3: Map of Soil Type in Ketar Watershed

River Discharge

Daily and monthly river discharge data of Ketar River at ABURA gauging station (KATAR Nr ABURA

(081019)) located at the near outlet of the study area from the year 1970 to 2010 is obtained from Ministry of Water, Hydrology and Irrigation Department of Ethiopia and is used for calibration and validation of SWAT model. For the daily time series of 1985 – 2005 year 99% of the river discharge is fully recorded.

Sub-Basin Discretization

Topography is a necessary input data in the SWAT model and is used in the delineation of the watershed and analysis of the land surface characteristics and drainage patterns. It influences the rate of movement and flow direction over the land surface. The digital elevation models (DEM) with 90 m by 90m ground resolution is used for derive the primary terrain attributes of slope and specific catchment area. The details of slope distribution in percent and DEM map are presented in the following table 5 and figure 3.

Table 5: Slope Ranges and Area Coverage in Ketar Watershed

Slope Range (%)	Area (Ha)	Area (%)
0-2	467.09	14.48
2-8	1628.98	50.50
8-15	751.77	23.31
15-30	333.34	10.34
> 30	44.09	1.37
Total	**3225.27**	**100.00**

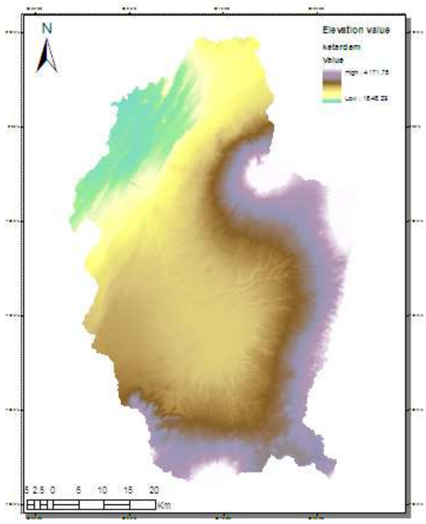

Figure 4: Digital Elevation Map of Ketar Watershed

Hydrological Response Units

Hydrologic response units (HRU) are parts of a sub-basin possessing unique combinations of land use, management or soil attributes and are incorporated into the SWAT model to account for the complexity of the landscape within the sub-basin (Neitsch et al., 2005). Watershed and sub-watershed delineation is carried out using the DEM and incorporating various steps like DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub-basin parameters. The resulting sub-watersheds were then divided into HRU based on the combinations of land use, soil type and the slope of the study area. Definition of HRU of Ketar watershed is performed by reclassifying and overlaying DEM, Land use map, Soil map and slope of the area using SWAT model on Arc map environment.

Model Sensitivity Analysis, Calibration and Validation

Model Sensitivity analysis is the step where the uncertainties of the modelling process, either due to model structure or the estimated parameter values, could be evaluated and prioritized for the inclusion in to the calibration process. Initially, Sensitivity analysis is to be conducted for the SWAT model's inbuilt procedures, and the most sensitive model parameters are to be identified. After the initial setup, the Sequential Uncertainty Fitting version 2 (SUFI-2) algorithms of SWAT Calibration and Uncertainty Programs (SWAT-CUP) an interface that was developed for SWAT was applied to re-identify the most sensitive model parameters and calibrate the model.

Using this generic interface (SWAT-CUP), many calibration/uncertainty or sensitivity program was reported. For instance, Singh et. al, (2013), applied the sequential uncertainty domain parameter fitting algorithm (SUFI-2) of SWAT CUP (calibration and uncertainty program) in Tungabhadra catchment in India, reported that, the resalt show excellent correlation during monthly calibration time steps, whereas daily calibration exhibits relatively good agreement between the observed and simulated flows. Kaleab and Manoj (2013), also applied semi automated Sequential Uncertainty Fitting (SUFI-2), for calibration and validation of runoff and sediment load in Gumera river basin upstream of Lake Tana, Ethiopia and obtained, a good model performance during calibration and validation time.

In this present work, after sensitive flow parameters are selected from SWAT model sensitivity analysis output, SWAT_CUP is set up with calibration parameters vide table 6, with their corresponding maximum and minimum value ranges. SWAT-CUP was iterated and the fitted values for the most sensitive parameters affecting the flow are identified.

Watershed hydrological modelling consists of three procedural steps, 1) Selection or development of a model structure, and subsequently computer code, 2) Calibration of the selected model structure and 3) Validation or verification of this model by applying it to a data set not used in the calibration stage.

Calibration is a process of parameter adjustment (automatic or manual), until observed and estimated output time-series show a sufficiently high degree of similarity. To apply models to evaluate impacts of land use and management practice on hydrological responses and sediment load in watershed, the model must be calibrated and validated with respect to observed data.

A good calibration and validation should involve: 1) observed data that include wet, average, and dry years, 2) multiple evaluation techniques; 3) calibrating all constituents to be evaluated and 4) verification that other important model outputs (Arnold et.al, (2012)). Validation involves running a model using parameters that were determined during the calibration process, and comparing the predictions to observed data not used in the calibration.

Calibration and validation of SWAT model is performed followed by sensitivity analysis for Ketar River flow at Abura flow monitoring station, which encloses an area of 3225.3 km^2 area coverage. The calibration procedure involved sensitivity analysis followed by semi-automated calibration procedure by SWAT-CUP, where, at times, manual manipulation on the selection of calibration parameters is required, as no automatic calibration procedure can substitute for actual physical knowledge of the watershed, which can translate into correct parameter ranges for different parts of the watershed as is suggested by Arnold, et al, 2012.

The availability of concurrent runoff and climate data primarily dictated the selection of time period used for model calibration and validation. Based on this, two time periods are selected, from 1985 to 1989 for calibration period and from 1991to1994 for the validation period, with two years 1983 and 1984 used as model warm-up period for model

initialization, which allows the model to cycle a number of times in an attempt to minimise the effects of the user's estimate of initial values of state variables at model start-up. The Nash–Sutcliffe Efficiency (NS_E) is used as an objective function to calibrate and validate the model using 12 flow sensitive input parameters included in the model structure, vide Table 6.

SWAT Model calibration is performed, using Sequential Uncertainty Fitting (SUFI-2) algorithm of SWAT-CUP, an interface extension developed for SWAT model. Sequential uncertainty fitting, Ver. 2 (SUFI-2) is an algorithm identifies a range for each parameter in such a way that upon propagation: 1) the 95% prediction uncertainty (95PPU) between the 2.5th and 97.5th percentiles contains a predefined percentage of the measured data, and 2) the average distance between the 2.5th and 97.5th prediction percentiles is less than the standard deviation of the measured data (Abbaspour, 2014).

Model Performance Evaluation Criteria

Results of the calibration and validation are evaluated based on the visual comparison of graphical representation and statistical criteria such as, Nash Sutcliffe Efficiency (NS_E) and Coefficient of Determination (R^2). There are also many other statistical criteria used to test model efficiency. They are includes, percent bias (PBIAS), Observation standard deviation ratio (RSR). Refer for detailed explanation of these methods indicated in (Moria et.al 2007).

RESULT AND DISCUSSIONS

Model Set Up and Watershed Delineation

Arc GIS and Arc SWAT software programs are used to delineate watershed and sub-watershed using topographic map (DEM) of 90m by 90m ground resolution. Model set up of Ketar watershed is done and stream is defined based on drainage area threshold of 9000 hectares, which is chosen from the possible range of values proposed by SWAT. Accordingly, 36 sub-watersheds of Ketar watershed are created. The total area of Ketar watershed is then determined to be 3225.3 Km^2. Based on model set up with Land use, Soil and slope and minimum area threshold values set as 5%, 10% and 10% respectively, 523 Hydrological Response Units (HRU) are identified, which are unique combinations of land use, soil type and slope.

Sensitivity Analysis

The sensitivities to the model performance give insight in parameter identifiability using the available information of daily stream flow data. In this research, initially a Latin Hyper cup one factor at a time (LHOAT) sensitivity analysis, which is incorporated in SWAT, is used to perform sensitivity analysis. After the initial setup, the Sequential Uncertainty Fitting version 2 (SUFI-2) algorithms of (SWAT-CUP), an interface developed for SWAT is applied to re-identify the most sensitive model parameters and calibrate the model.

Table 6: SWAT Calibration Parameters with their Respective Sensitivity Ranks and Fitted Values

Parameters	Descriptions and Units	Sensitivity Rank	Range Values		Fitted Values
			Minimum	Maximum	
CN_2	Initial Soil Conservation Service (SCS) runoff curve number for moisture condition II	4	35	98	70.70
SURLAG	Surface runoff lag coefficient	6	0	24	0.59

Table 6: Contd.,					
SOL_AWC	Available water capacity of the soil layer (mm/mm soil)	5	0	1	0.025
SOL_K	Soil conductivity (mm/hr)	2	0	2000	500
EPCO	Plant evaporation compensation factor	12	0	1	0.898
ESCO	Soil evaporation compensation factor	8	0	1	0.094
ALPHA_BF	Base flow alpha factor (days)	11	0	1	0.0
GW_DELAY	Ground water delay (days)	9	0	500	132
GW_REVAP	Groundwater“revap” coefficient	3	0.02	0.2	0.058
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	7	0	5000	533
HRU_SLP	Average slope steepness (m/m)	10	0	0.6	0.416
CH_K_2	Effective hydraulic conductivity in main channel (mm/hr)	1	-0.01	500	9.90

The results of the analysis indicate that, twelve parameters viz, Curve Number (CN2), Ground flow recession factor (ALPHA_BF), Soil Evaporation Compensation coefficient (ESCO), Plant Evaporation Compensation Coefficient (EPCO), Soil Available Water Capacity (SOL_AWC), Soil Hydraulic conductivity (SOL_K), Hydraulic conductivity in main channel (CH_K2), Surface runoff lag coefficient SURLAG, Average slop steepness (HRU_SLP), Groundwater “revap” coefficient (GW_REVAP), Threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN) and Ground water Delay (GW_DELAY) are the most essential parameters for the studied watershed vide table 6. The sensitivity analysis indicated the overall importance of the twelve parameters in determining the stream flow at the study area, but CH_K2 and SOL_K were found to be the most sensitive parameters than others.

Model Calibration and Validation

Model Calibration and validation of Ketar watershed is performed using Sequential Uncertainty Fitting (SUFI-2) algorithm of SWAT-CUP. The model is forced to run 500 times iteratively in both period (Calibration and validation). The result obtained are shown in figure 4 and figure 5 and table 7 show that there is good agreement between monthly simulated and measured stream flow in both graphical and statistical comparison.

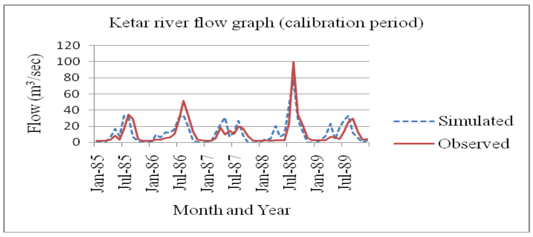

Figure 4: Mean Monthly Simulated and Observed Ketar River Flow during Calibration Period (1985-1989) at Abura Station

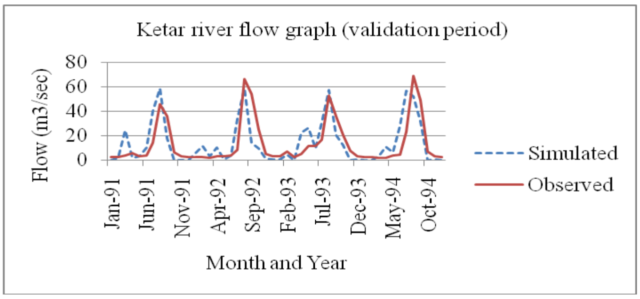

Figure 5: Monthly Simulated and Observed Ketar River Flow During Validation Period (1991-1994) at Abura Station

The above graphical representations clearly show that, there is good agreement between model simulation and observed flow of Ketar River at an outlet. The models are able to capture peak flow during calibration and validation periods. The mean monthly simulated and observed discharge shows almost similar pattern in both calibration and validation period. This result is proved using well known model evaluation criteria recommended by several researchers. One well known model evaluation criteria is Nash-Sutcliffe coefficient (NS_E) indicate that, the model performs very good during calibration and good during validation period; i.e., NS_E is 0.78 during calibration and 0.66 during validation period (Table 7). The performance remarks given in the following table 7 are based on the classification given by (Moria et.al. 2007).

Table 7: SWAT-CUP Simulation Results during Calibration Period (1985-1989) and Validation Periods (1991-1994)

Evaluation Parameters	Simulation results		Performance Remarks	
	Calibration	Validation	Calibration	Validation
NS_E	0.78	0.66	V.G	G
R^2	0.80	0.70	V.G	G
PBIAS	13.9	5.1	G	V.G
RSR	0.47	0.62	V.G	S.

V.G= Very Good, G. = Good, and S. = Satisfactory

Overall performance of the model is found to be satisfactory.

The performance efficiency values in both calibration and validation period prove that, SWAT model predicted monthly stream flow quite satisfactorily against measured stream flow. As indicated in the Table 7, monthly coefficient of determination value (R^2) is 0.80 during calibration and 0.70 during validation period. This shows very good predictive capacity of the model to reproduce similar river flow at outlet. This graphical interpretation together with the numerical analysis gives a comprehensive measure of the agreement between measured and simulated data

CONCLUSIONS

SWAT model is applied to Ketar watershed in order to evaluate its simulating capacity through calibration and validation using Sequential Uncertainty Fitting (SUFI-2) algorithm of SWAT-CUP in monthly time series. The model is subjected to two well known goodness of fit i.e., NS_E and R^2. The hydrological model enables to trace the variation of runoff in terms of seasonal regime of monthly time period. In general, there is a good agreement between monthly simulated and measured stream flow during calibration and validation period. Therefore, it is proved to use the model for further simulations and analysis of Land use/land cover change on hydrological regime of Ketar watershed for future research.

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